IHO- Data Quality Working Group

27 May, 2015

Paper for Consideration by DQWG

Satellite Derived Bathymetry

Submitted by:	UK
Executive Summary:	UKHO presented a paper on Satellite Derived Bathymetry (SDB) to the NCWG on 28 April 2015. The paper considered standardization and guidance in S-4 for the representation of SDB data on paper charts and ENCs. The NCWG recommended for the paper to be presented to the DQWG before any final decisions are made. The DQWG are invited to feedback comments to the NCWG on the following paper.
Related Documents:	S-4; INT1
Related Projects:	None

1. Introduction

Satellite Derived Bathymetry (SDB) refers to depths processed from optical satellite imagery.

UKHO considers that good quality SDB data, used appropriately, is able to provide valid information that can be used to make navigational products safer. UKHO have been assessing the accuracy of SDB and the most suitable methodology for representing SDB data on charts. The aim is to have the ability to be able to quality control and use SDB data as source data for navigational products. This will allow UKHO to make use of this technology in areas where modern survey data is lacking and more conventional methods would prove too difficult or not cost effective.

SDB was developed in the late 1970s, but recent advances in satellite technology, such as improved resolution and multi-spectral bands, have increased its potential as a source of hydrographic data. The use of SDB data is increasing throughout the hydrographic industry as a low cost source of data.

In general, SDB data can offer:

1. **Good coverage** (within depth and image limitations); not as good as Multi-beam echo sounder (MBES), some objects may be missed, but better than single-beam echo sounders (SBES) and leadline.
2. **Better object detection than leadline**, but not as good as SBES used with side scan sonar or a MBES.
3. **Good positional accuracy**. Similar to MBES and SBES. Better than historic leadline.
4. **Lesser depth accuracy** than MBES, SBES and leadline.

Questions considered by UKHO:

1. The depth accuracy is where the technology has limitations and this needs to be understood to the same level of conventional survey techniques (leadline, echo-sounder, etc.). How accurate is it really?
2. How can this data be depicted on charts to ensure that the depth accuracy limitations are understood and it is used appropriately by the mariner? Is existing symbology enough or is something new required? Are standards needed to ensure consistency throughout the IHO?

This paper gives a summary of the UKHO research into the accuracy of SDB and goes on to recommend options for representation of SDB data on paper charts and ENCs.

2. Background

SDB is based on the expectation that deeper water appears darker than shallower water. This simple analogy is complicated however as a shallow black rock can appear darker than surrounding deeper sandy seabed. Complex mathematical analysis of the imagery attempts to distinguish these differences and remove the many other sources of 'noise' in a satellite image and produce a best estimate for the average depth in each pixel.

Satellite imagery is available at many different resolutions (+100m to 31cm). Only imagery of a resolution higher than 30m is suitable (and appropriate) for charting, as SDB results in an average depth per pixel. Even when using 30m resolution imagery the results should be used with caution as many shoal depths may not have been detected. SDB processing requires multispectral imagery, which in the commercial sector is currently limited to a maximum resolution of 1.24m (WorldView-3). Higher resolution imagery is usually black and white and not able to provide SDB.

Unlike "active" depth measurement techniques such as echo sounders or Light Detection and Ranging (Lidar), where controlled signals are transmitted and received, SDB is a "passive" technology and is simply measuring the reflected sunlight intensity. Because of this, SDB results are affected by many more uncontrollable environmental factors.

SDB is limited to shallow clear waters where the seabed can be seen in the imagery. Its results can be adjusted and improved by providing "ground truth" data using more conventional survey techniques (e.g. echo sounder).

Industry claims of accuracies of 10% of depth were not borne out by early experiences of SDB within the UKHO. UKHO decided in 2013 to conduct a controlled trial to fully understand the accuracy and reliability of SDB.

3. UKHO SDB Trial

3.1. Goals

To allow the UKHO to make an informed decision regarding the suitability of SDB as a data source for navigational products and, at the same time, gain an understanding regarding the optimal parameters for SDB data acquisition.

3.2. Method

To acquire the best quality MBES and SDB data within a given area and compare them, using the MBES data as the benchmark.

UKHO conducted a high resolution, high quality, MBES survey along the south coast of Antigua in September 2013. This area was chosen for the trial as it offered clear water with a range of depths and a mix of simple sand and complex coral seabed.

The MBES data typically met the vertical and horizontal uncertainty requirements for S44 “special order”, the object detection requirements for S44 “Order 1a” and CATZOC A1.

Satellite imagery was tasked with optimal parameters and acquisition that took place during the MBES survey in order to remove any doubt that the seabed could have changed. Imagery was acquired from the Worldview-2 satellite, one of the most advanced civilian imagery satellites available at the time of the trial, with a pixel resolution of 2m.

The imagery was processed using several different SDB processing methods, both in-house and through commercial companies, in order to compare them and understand the repeatability of this technology.

All data was corrected to chart datum using observed tides.

3.3. Results

Results were looked at in terms of both overall accuracy (compared to MBES dataset) and SDB’s ability to define critical soundings. These factors were then used to assess a suitable CATZOC classification for SDB data. All the conclusions are based on the most accurate SDB dataset from the trial (which was provided by ground truthed data from one of the external companies).

A series of profiles were taken showing the MBES data against different versions of the SDB data. These are shown below and indicate that SDB is able to detect the general shape of the seabed.

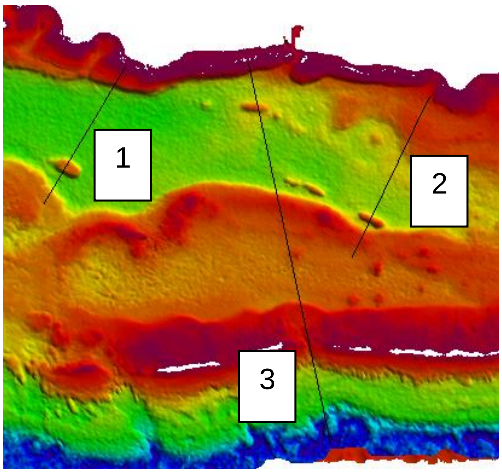


Figure 1 - SDB data showing the location of the profiles

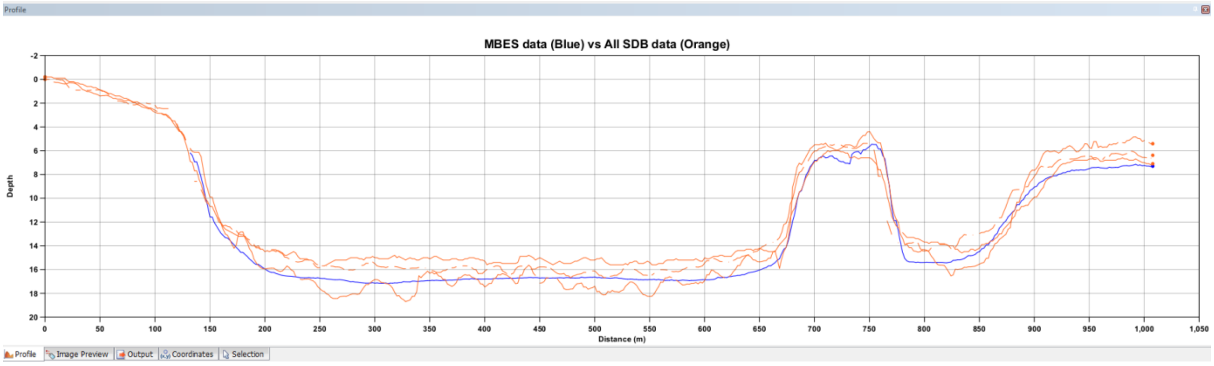


Figure 2 – Profile 1 - MBES data (blue), All SDB data (orange)

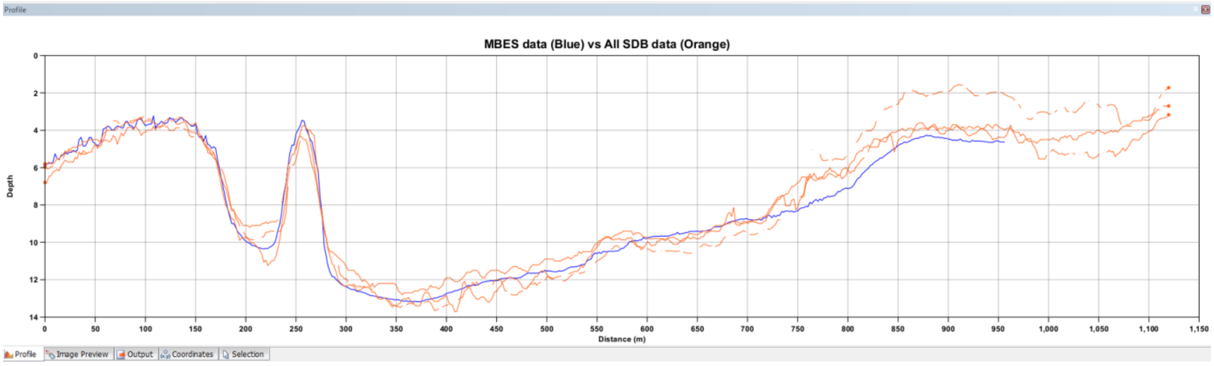


Figure 3 - Profile 2 - MBES data (blue), All SDB data (orange)

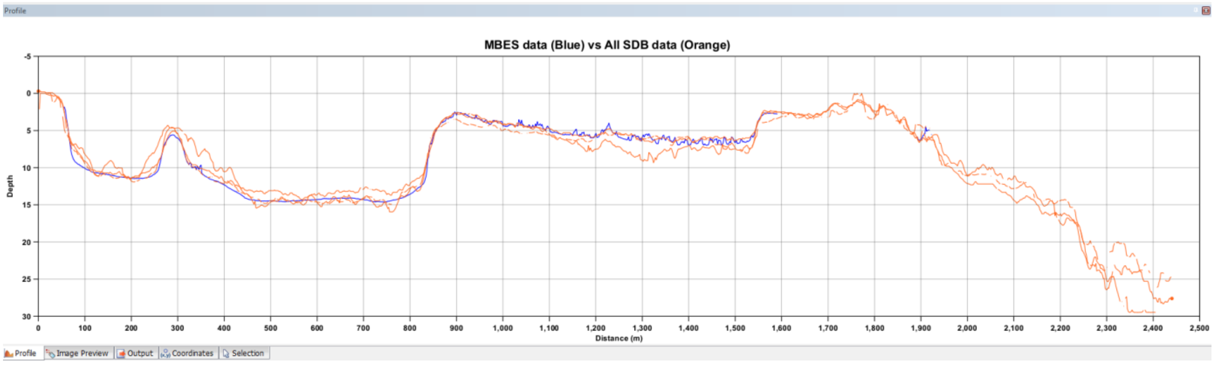


Figure 4 - Profile 3 - MBES data (blue), All SDB data (orange)

The most significant soundings from the MBES and the SDB data were compared and these are shown in the figures below. The area was previously charted using only leadline data. Three critical soundings were identified from the MBES data (as highlighted with the white arrows). These were also detected in the SDB data and depths were within 0.7m of the MBES data. Other soundings shown are within 2m of the MBES data.

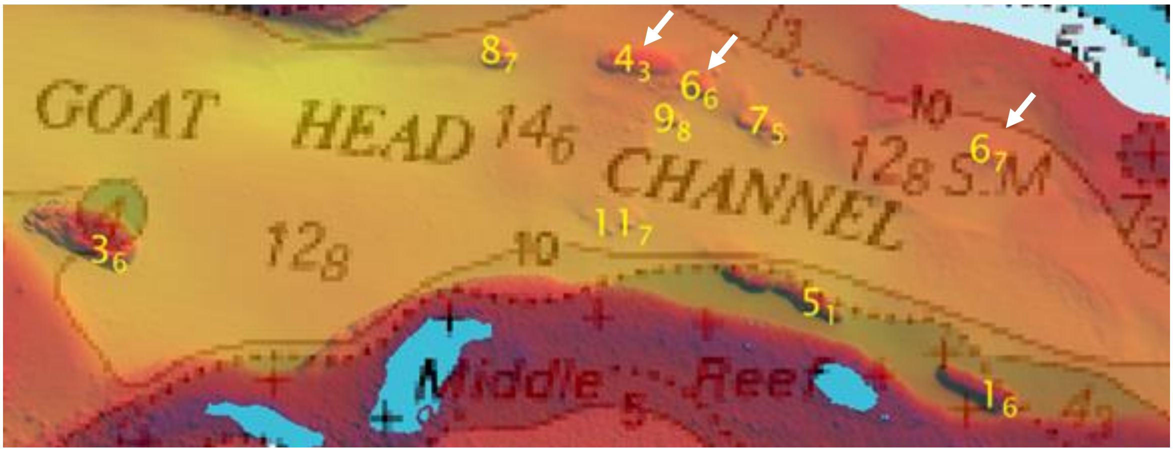


Figure 5 - MBES depths

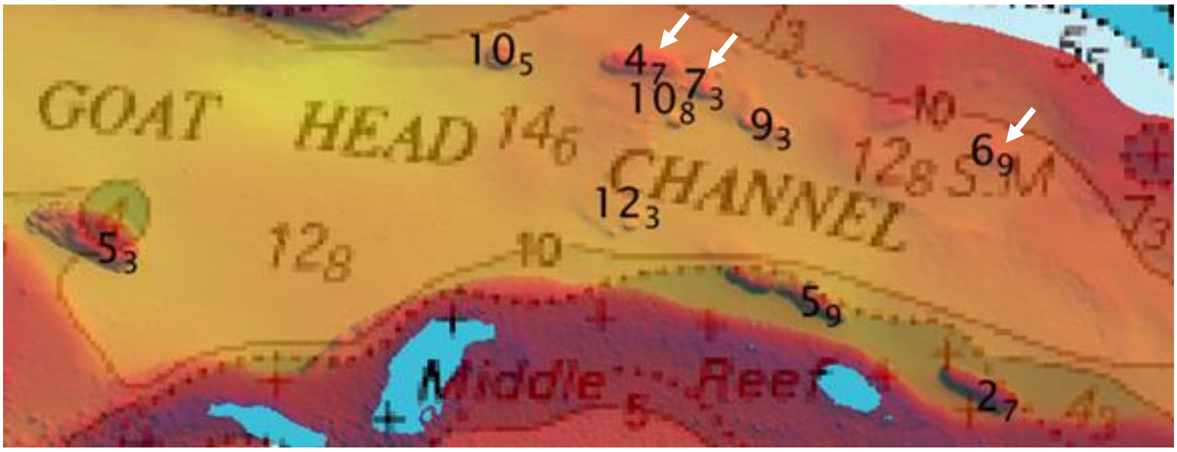


Figure 6 - SDB depths

Difference surfaces were created and coloured to show areas where the SDB data is within 2m and 3m of the MBES data. These are shown in the figures below.

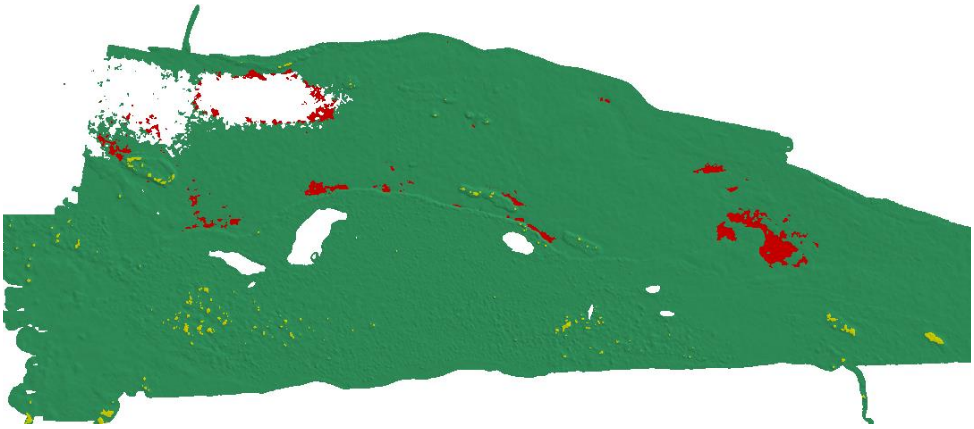


Figure 7 - Green SDB is within ±2m to MBES. Yellow SDB is deeper. Red SDB is shoaler

Figure 8 - Green SDB is within ±3m to MBES. Yellow SDB is deeper. Red SDB is shoaler

The difference surfaces were compared to the depth accuracy requirements for CATZOC C. It was found that for the best data set from the trial (which had ground truth data applied to improve the results) more than 97% of the SDB data was within the CATZOC C depth accuracy requirements. Without ground truth data applied only 79% of the SDB data met CATZOC C requirements. With a horizontal accuracy of ~5m all the SDB data easily meets the horizontal accuracy requirements for CATZOC C (500m).

3.4. Conclusions

Like a conventional hydrographic survey, different processing methods make a clear difference to the SDB data. Validation of both source imagery and processing is required to ensure optimal results are achieved.

Using ground truth data improved the SDB results. Though ground truth data can be relatively sparse in survey terms, ideally it should be spread over the area and include data near the extents of the SDB data. It should also include data extending to the min and max depth range of the SDB data.

The uncertainty of the SDB data increased with depth. In the case of this trial, only SDB data shallower than 16m was considered reliable. It is expected that this ‘cut-off’ depth would be different for data acquired in different areas and from different imagery. The actual cut-off depth can only be determined reliably using ground truth data.

The SDB trial data does not meet IHO S-44 survey standards. Though more than 97% of the “Commercial Company 1” data could be categorised as CATZOC C, the data that fails CATZOC C requirements is spread throughout the data set and would be difficult to delineate. SDB has detected the majority of features though, which is in the spirit of CATZOC C, and unlike traditional CATZOC C data, such as leadline, does not consist of large areas where no data exists at all. Until further work has been done on quality control parameters and error budgets, ground truthing would be required to prove that CATZOC C had been attained.

The trial SDB data was accurate to approximately ±2-3m when compared to the MBES data, though much of the data was better than this.

Though SDB technology is not able to match echo sounders for depth accuracy it can give an indication of the shape of the seabed. It is likely that some features will be missed and though the technology can obtain depths as deep as the water clarity will allow, the reliability of these depths greatly decreases as the depth increases.

This trial was conducted in waters that are favourable for the use of SDB and using high resolution imagery. Further work is needed to assess the performance of SDB in less favourable conditions and with lower resolution imagery.

In this case, the ground truthed SDB data was capable of making the chart safer.

4. Representing SDB on charts

UKHO consulted a representative panel of mariners from across the shipping industry for their opinion on the representation of SDB data on charts.

The general opinion was that they would like to know where SDB survey data is used on a chart, but there was a preference not to use any additional symbology over and above the standard depiction of soundings. There was a preference to use the source diagram and chart notes to assess the level of confidence with survey data.

UKHO considered various options for charting SDB data. These are summarized at Annex A.

Taking account of the mariner opinions and our own internal analysis and discussion, UKHO has determined that there is no requirement to differentiate soundings derived from satellite bathymetry on the chart face itself. This is due to the observed level of data accuracy (see CATZOC analysis at 3.3 above). Instead, as with data from all traditional origins, we are proposing to bring areas of satellite derived bathymetry to the mariners attention using the source diagram on the chart, stating the method of acquisition used and the date of survey. However, noting that the mariners also requested chart notes and the fact that the shortcomings of this new data source are not widely understood within the industry, UKHO considers that a chart note should be included, for example:

SATELLITE DERIVED DEPTHS

> Depths within the area indicated on the [source diagram/chart] are mainly derived from satellite imagery. Their vertical accuracy is typically [± 3m]. Uncharted dangers may exist.

An associated legend '*Depths (see Note)*' and (where the extent of the area may not be sufficiently delineated on the source diagram) an area limit using existing INT1 I25 should also be included.

5. Conclusions from the trial

As with all survey techniques, it is possible to acquire both good and bad SDB data. In the UKHO trial it was shown how ground truthing can greatly improve SDB results and also provide evidence of the data meeting an IHO standard. The results of the trial don't imply that all SDB is fit for charting, only where best practices have been followed.

Though confidence in SDB data is lower than echo sounder surveys, SDB data is capable of providing useful information at least as good as leadline survey data. Leadline surveys do not necessarily find all the shoals in an area due to the technique and the same can be said for SDB but for different reasons.

Good SDB data can be of value when navigating but the mariner needs to understand the uncertainty of the data and how it differs from surrounding data in order to use it appropriately.

New symbology is not required to represent SDB data on paper charts and ENC.

Though S-4 covers the delineation of shoal areas from satellite imagery (B-424.7) it doesn't include any guidance where depths can actually be derived from the imagery and how these depths should be depicted. UKHO now believes that actual depths from SDB data, not just the depiction of shoal areas, can be valid data for charts, so charting guidance is now required.

6. Recommendations for charting SDB data

Guidance on the use of SDB data on charts should be included in S-4. A new sub-section at B-417.9 is suggested. B-424 is not suitable, as this deals specifically with 'doubtful dangers', but there should be a cross reference to and from B-424.7. The new sub-section should include the following points:

a. SDB data should be validated by conventionally obtained data (e.g. by echo sounder), known as ground truthing and if it can be proven thereby to be sufficiently accurate, assigned a maximum of CATZOC C on ENCs and depicted using standard italic black soundings on paper charts.

b. Ground truth data should be gathered to at least the horizontal and depth accuracy requirements of IHO S44 order 1b and spread over the area to include data near the extents of the SDB data. It should also include data extending to the min and max depth range of the SDB data.

c. Caution should be given to any SDB data where the provenance of the imagery is not known and ground truthing has not been conducted.

d. SDB data should not be used to disprove existing charted shoal depths, but it may be used to improve the position of shoals derived from surveys based on old positioning methods.

e. Any dangers discovered by SDB should be charted but it should not be implied that further dangers do not exist.

f. Source diagrams should identify where SDB data has been used and reference the date of the imagery acquisition (not the date the bathymetry was computed).

g. Notes should be added to charts explaining the shortcomings of SDB data.

h. Areas containing mainly SDB data may exceptionally be identified on the face of the chart by a limit if: there is no source diagram or it is considered that the Source Diagram cannot depict it accurately enough; where the provenance of the imagery is not known; where the vertical accuracy cannot be assessed because ground truth data has not been obtained.

7. Justifications and Impacts

UKHO have proved that good quality SDB data can fit into current IHO standards and symbology, but it is important that it is represented consistently on charts to avoid confusion to the mariner. If used appropriately, SDB added to a chart can reduce the risk of navigating a certain area, whereas SDB used inappropriately could increase the risk of navigating the same area.

8. Action required of NCWG and DQWG

The NCWG is invited to agree standards and guidance for the depiction of SDB data on nautical charts.

DQWG is invited to feedback comments to NCWG to assist with their decision.

Reviewers

Name	Role	Date reviewed	Version reviewed
Nick Webb	Geographic and Data Acquisition Manager	02/06/15	V1
Andrew Heath-Coleman	Senior Cartographer and Secretary IHO-NCWG	02/06/15	V1
Edward Hosken	Head of Technical Engagement	03/06/15	V1

Annex A

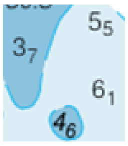
Options for charting SDB depth data considered by UKHO

Paper charts

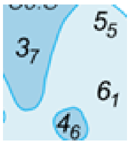
UKHO considered possibilities using IHO standard symbology and non-standard symbology:

<u>*Using existing IHO symbology:*</u>

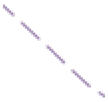
1. *Upright black soundings (INT1 I14) (existing depths retained in normal black)*



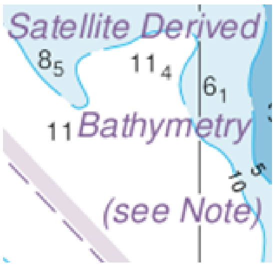
2. *Normal black soundings.*



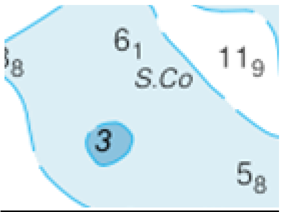
3. *Areas of SDB to be delineated by a boundary, dashed 'black or magenta' line (I25) with or without highlighting tint band (N1).*



4. *Legend placed within the limits of the SDB data "Satellite Derived Bathymetry (see note)"*

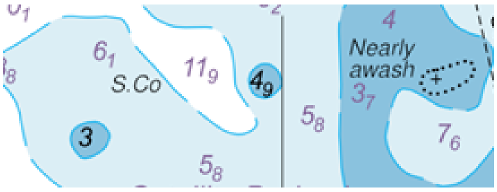


5. *Dashed "approximate depth" contours (I31).*



<u>Using non-standard symbology:</u>

1. *Magenta soundings (existing depths retained in normal black)*



ENC

All depths on ENCs look the same and the only current way to distinguish between them is through underlying S-57 data.

One of the quality attributes in S-57 is CATZOC. Given the current state of SDB technology it is proposed that the highest CATZOC that could be assigned to SDB data is CATZOC C. The UKHO SDB trial provided evidence that backs this up. CATZOC C is normally used for leadline data and is described by the IHO as follows:

"Full area search not achieved, depth anomalies may be expected."

"Low accuracy survey or data collected on an opportunity basis such as soundings on passage."

"Depth accuracy need not be rigorously computed for ZOCs B, C and D but may be estimated based on type of equipment, calibration regime, historical accuracy etc."

CATZOC C should only be allocated to SDB where the provenance and metadata of the source satellite image is known and the SDB data is backed up with redundancy (e.g. ground truth data), otherwise CATZOC D should be assigned.